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IMPACT OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION AND AGROCLIMATIC CONDITIONS IN THE PIROT VALLEY

Nataša Martić Bursać

University of Niš, Faculty of Science and Mathematics,
Department of Geography, Republic of Serbia
✉ *natasam@pmf.ni.ac.rs*

Ljiljana Stričević

University of Niš, Faculty of Science and Mathematics,
Department of Geography, Republic of Serbia
✉ *ljiljanastricevic@pmf.ni.ac.rs*

Milena Gocić

University of Niš, Faculty of Science and Mathematics,
Department of Geography, Republic of Serbia
✉ *milena.j.gocic@gmail.com*

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Abstract: This research is motivated by the fact that climate change has significantly impacted various facets of the environment and society in recent decades. One of the most vulnerable sectors to climate change is agriculture, as it heavily relies on weather conditions. The rise in global temperatures and the increasing frequency of extreme weather events have triggered significant changes in plant life, impacting their physiology, distribution, and abundance. Together, these factors result in alterations in the agroclimatic conditions of agricultural production. The objective of this study is to investigate whether similar changes are present in the Pirot valley, given that climatic conditions, alongside geographic location and soil quality, are critical for successful cultivation of crops and achieving high yields. The analysis utilizes data from the Republic Hydrometeorological Service of Serbia for Pirot meteorological station spanning the period 1961-2020. A comprehensive analysis was conducted on monthly and annual temperature and precipitation patterns, accompanied by an assessment of agroclimatic indices and their trends. Furthermore, a comparative analysis of two standard climatological periods, 1961-1990 and 1991-2020, demonstrated the evident impact of climate change, directly influencing the quality, quantity, and overall development of agriculture in the Pirot Valley.

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1. Introduction

In recent decades, a wide range of economic sectors and industries have been affected by global climate change. The most sensitive primary sector is agriculture, as it heavily relies on the changing environmental conditions due to climate shifts. The geographical position, soil quality, and land cover predominantly determine the suitability of a specific area for agricultural production. However, climate features, such as sunlight hours, average temperature, the volume and type of precipitation, wind, humidity, etc., are the most influential factors on agricultural production and development. They impact crop choices, production methods, and yields (Đurić & Njegovan, 2016). Thus, it is essential to pay great attention to the study of agroclimatic characteristics. Climate changes primarily manifest in rising global air temperatures and altered rainfall patterns. Some of these changes include an increase in the frequency of extreme events and severe weather, such as heatwaves, droughts, storms, frost, floods, landslides, wildfires, and more.

Undoubtedly, the root cause of climate change, and consequently, the escalation of extreme events over the past few decades, is rooted in human activity. Human actions have significantly contributed to the increase in greenhouse gases and changes in the atmospheric composition. The rise in carbon dioxide concentration in the atmosphere is primarily attributed to the extensive use of fossil fuels. These activities have created conditions for changes in other spheres of the Earth, particularly the biosphere, resulting in negative impacts on all life on our planet.

The consequences of climate change in agriculture are observed through their effects on plants and animals, leading to functional shifts and alterations in their abundance and distribution. Changes in the timing of phenophases of crops, particularly the beginning and duration of the vegetation period, increase the risk of frost, representing some of the consequences. Moreover, rising temperatures, droughts, and the increasing frequency of hailstorms have a detrimental impact on the quality of fruits and vegetables, resulting in reduced yields. It is highly probable that the impact of climate change will significantly intensify on agricultural production in the near future. As per estimates, corn yields in Serbia are projected to decrease by approximately 50% by the end of the century (Popović & Vuković, 2019).

2. Theoretical Framework

The Pirot Valley is located in eastern Serbia, encompassed by the administrative boundaries of the City of Pirot, and constitutes the integral part of the Pirot Administrative District, together with the municipalities of Dimitrovgrad, Babušnica, and Bela Palanka. In the context of regional geography of Serbia, it falls within the Southern Serbia region, as a part of the Eastern or Outer zone of the Carpathian-Balkan Mountains.

The Pirot Valley is a vast basin in Balkan Serbia, positioned centrally in the Upper Ponišavlje region and represents the foremost basin within the composite valley of the Nišava River. The average elevation ranges from 320 to 400 meters. Extending from northwest to southwest, the valley stretches from the Sopot Gorge to the point of confluence between the Jerma River and the Nišava River, and also encompasses a narrower segment on its right side near the settlement of Sopot, reaching up to the Temštica River. It has a length of approximately 20 km and a width of around 12 km (Pavlović, 2018; Đokić, 2020; Rodić & Pavlović, 1994; Janković, 1909; Petrović, 1999). It is encircled by the Vidlič, Basarski Kamen, and Crni Vrh mountains on the northeast, while the Vlaška Mountain encloses it from the southwest, continuing northwestward to Golaš and Šljivovički Vrh mountains. The valley covers an area of around 12,000 hectares, with approximately 8,000 hectares comprising flatland terrain (Stojković & Radonjić, 2017).

The Pirot Valley benefits from a favorable geographical position and exceptionally abundant natural resources for agricultural development, including high-quality soil, favorable climatic conditions, and abundant water resources. Previous research has indicated that the Pirot Valley exhibits a climate characteristic of Balkan Serbia, comprised of blend of basin and sub-mountain climates, with a significant continental influence influenced by neighboring basins - Vlaško-pontijski, Panonski, and Egejski.

The climate of the region can be described as temperate continental, with moderately warm summers and cold winters. However, during the colder part of the year, a modified Mediterranean climate influences the area, leading to the influx of warm air masses from the southeast. The position of the Vidlič mountain massif plays a crucial role in shaping these weather conditions. It acts as a natural barrier, preventing the intrusion of cold air masses from the northeast, resulting in mild winters, while autumns tend to be warmer than springs. On the contrary, the mountain ranges closing the valley from the southwest hinder the penetration of moist air masses, leading to relatively low annual precipitation, approximately 600 mm, which is unevenly distributed throughout the year.

In the mountainous periphery of the valley, at elevations of 1200-1800 meters, a belt of cold and snowy boreal mountain climate prevails, characterized by average annual temperatures ranging from 4 to 7°C and annual precipitation ranging from 950 to 1100 mm (Petrović, 1999; Stanković, 1996; Ducić & Radovanović, 2005).

According to the Rakičević's climate classification (1980), the Pirot Valley falls within the Ponišavski region, which experiences a slightly harsher climate compared to the Niš-Leskovac region. Moving from west to east, the average annual temperatures decrease, while the annual amount of precipitation increases, primarily due to the rise in altitude.

The Pirot Valley's agricultural potential is primarily derived from its rich Neogene sediments and river deposits found in the valleys. These areas are extensively cultivated, with arable lands, orchards, and vineyards being the dominant agricultural practices. Cereal and vegetable crops are the most prevalent, with fewer industrial crops cultivated (Marković, 1966). Within the City of Pirot's territory, agricultural land covers 56.7% of the total area. The land usage composition consists of 44.8% pastures, 29.8% arable lands, 20.1% meadows, and the remainder allocated to vineyards and orchards. As of 2005, cereals account for 52.2% of the arable lands, fodder crops for livestock 27.4%, vegetables 10.6%, industrial crops 0.9%, and non-cultivated areas 8.9%. Corn is cultivated on an average of around 5,000 hectares annually, with approximately 99% of the corn yield used as livestock feed (Stojković & Radonjić, 2017).

Climate change gives rise to a myriad of challenges in agriculture, with drought emerging as a foremost concern due to its direct repercussions on the growth, development, and yields of agricultural crops. The impact of drought on plants is contingent upon the timing, duration, and intensity of the water scarcity. Insufficient water availability in plants influences their physiological and biochemical processes. While some plant species exhibit a remarkable ability to adapt to drought conditions by acclimating to the altered environmental conditions, many others lack this adaptive capacity, resulting in shifts in their geographical distribution towards more humid regions or, in some cases, leading to their complete demise and extinction (Ruml, 2005).

3. Methodology

Contemporary intensive agricultural production relies heavily on the application of agrometeorological data and phenological observations, which play a crucial role in various aspects of production planning. These include soil preparation and cultivation, the careful selection of crop types and varieties to maximize yields, efficient irrigation strategies, effective crop protection against diseases and pests, accurate determination of sowing and harvesting dates, as well as the timing and duration of specific phenophases. Additionally, agrometeorological information is instrumental in ensuring proper storage and transportation of agricultural products, among other essential considerations.

To comprehensively investigate the agroclimatic conditions of the Pirot Valley, official data from the Republic Hydrometeorological Service of Serbia (RHMZ, 2023) for the Pirot meteorological station (elevation: 370 m above sea level) were utilized in this study. The data spanned a period of 60 years, from 1961 to 2020, with a comparative analysis conducted for two standard climatological periods of 30 years each, covering the years 1961 to 1990 and 1991 to 2020.

Given that temperature and precipitation regimes play a fundamental role in defining the climate and agroclimatic conditions of a specific area, a detailed analysis of temperature and precipitation data was conducted to derive various agroclimatic indices.

The temperature regime was defined based on the monthly and yearly averages of air temperature, as well as the average maximum and minimum air temperatures observed throughout all three observational periods.

Regarding the precipitation regime, we analyzed the annual and monthly precipitation data across all three observational periods.

To gain a comprehensive understanding of the specific climate characteristics of the studied region, particularly its agroclimatic conditions, we utilized a combination of climatic elements known as climatic indices. These indices offer a holistic characterization of the climate at the given location, encompassing both quantitative and qualitative aspects (Burić et al., 2007).

To assess the agroclimatic conditions of the Pirot Valley, with a specific focus on determining the level of climate aridity, geophysical classifications by Azzi and Gračanin were employed, and specific indices were computed, including Lang's rainfall factor, Gračanin's rainfall factor, and De Martonne's aridity index.

Geophysical climate classification was carried out based on individual climatic elements. Azzi (1952) divided the climate based on annual precipitation, while Gračanin (1950) used mean annual air temperature for classification, and their classifications are presented in Table 1.

Table 1. Geophysical climate classification based on the annual precipitation (Azzi) and average annual air temperature (Gračanin).

Classification by Azzi		Classification by Grachanin	
Total annual precipitation (mm)	Climatic classification	Mean annual air temperature (°C)	Climatic classification
< 250	Arid	< 0.5	Nival
250 – 500	Semiarid	0.5 – 4.0	Cold
500 – 1000	Subhumid	4.0 – 8.0	Moderately cold
1000 – 1500	Humid	8.0 – 12.0	Moderately warm
> 1500	Perihumid	12.0 – 20.0	Warm
		> 20.0	Hot

Source: Azzi (1952); Gračanin (1950)

Nevertheless, these classifications have limitations as they do not consider other influential factors and elements that contribute to the climate of a specific area, potentially leading to misconceptions about its climatic conditions. In this research, these classifications were determined to gain a broader understanding of the studied region.

The Lang's rainfall factor is a valuable metric used to assess the level of climate aridity on an annual basis. It is derived by calculating the ratio of the mean annual precipitation P_{ann} to the mean annual air temperature T_{ann} (1). The classification of Lang's rainfall factor, along with its associated climatic regions and vegetation types, can be found in Table 2 (Burić et al., 2007; Martić Bursać & Stričević, 2018; Ducić & Anđelković, 2004). This classification provides important insights into the climatic characteristics of the studied region and helps in understanding its aridity patterns.

$$Pf_L = \frac{P_{ann}}{T_{ann}} \qquad (1)$$

Table 2. Classification of Lang's Rainfall Factor

Lang's Rainfall Factor	Climatic classification	Vegetation
$Pf_L \leq 20$	Severely Arid	Desert
$20 < Pf_L \leq 40$	Arid	Semi-desert
$40 < Pf_L \leq 60$	Semiarid	Steppe and savanna
$60 < Pf_L \leq 100$	Semihumid	Sparse forests
$100 < Pf_L \leq 160$	Humid	Rainforests
$Pf_L > 160$	Perihumid	Tundra

Source: Ducić & Andjelokvić (2004)

The annual Gracanin's Rainfall Factor is computed similarly to Lang's, with a slightly different classification. The monthly Gracanin's Rainfall Factor assesses the degree of climate aridity on a monthly basis, determined by the ratio of average monthly precipitation P_{mth} to average monthly temperature T_{mth} (2). For months with average monthly temperatures at or below 0°C, the formula (2) becomes inadequate, and instead, the average temperature of the frost-free period T_{nfm} is used. In Pirot's case, the frost-free period is considered from March to October, and the formula (3) is used to calculate the index for January, February, November, and December.

$$Pf_{Gm} = \frac{P_{mth}}{T_{mth}} \qquad (2)$$

$$Pf_{Gm} = \frac{P_{mth}}{T_{nfm}} \qquad (3)$$

The classification of Gracanin's Rainfall Factor, both annually and monthly, along with their characteristic climate types, is presented in Table 3 (Komljenić & Kondić, 2011; Rajić & Zemunac, 2017).

Table 3. Classification of Gracanin's Rainfall Factor

Annual Gracanin's Rainfall Factor	Monthly Gracanin's Rainfall Factor	Climatic classification
$Pf_G \leq 40$	$Pf_{Gm} \leq 3.3$	Arid
$40 < Pf_G \leq 60$	$3.3 < Pf_{Gm} \leq 5$	Semiarid
$60 < Pf_G \leq 80$	$5 < Pf_{Gm} \leq 6.6$	Semihumid
$80 < Pf_G \leq 160$	$6.6 < Pf_{Gm} \leq 13.3$	Humid
$Pf_G > 160$	$Pf_{Gm} > 13.3$	Perihumid

Source: Rajić & Zemunac (2017); Komljenić & Kondić (2011)

The De Martonne Aridity Index serves as a valuable indicator of climate aridity in a specific region, establishing the correlation between precipitation and temperature on the one hand and landscape characteristics associated with moisture and vegetation on the other. The annual De Martonne Aridity Index $IdM_{(ann)}$ is calculated as the ratio of the annual precipitation P_{ann} to the mean annual air temperature T_{ann} increased by 10°C to prevent negative values (4). Similarly, the monthly De Martonne Aridity Index $IdM_{(mth)}$ is computed using the formula (5), multiplying monthly precipitation by 12 to enable direct comparison with the annual index. Table 4 presents the classification of the De Martonne Aridity Index, accompanied by the corresponding landscape units and vegetation types (Martić Bursać & Stričević, 2018; Ducić & Anđelković, 2004). This classification provides valuable insights into the aridity levels of different regions and their associated landscape and vegetation characteristics.

$$IdM_{(ann)} = \frac{P_{ann}}{T_{ann} + 10\ ^{0}\mathrm{C}} \qquad (4)$$

$$IdM_{(mth)} = \frac{12 \cdot P_{mth}}{T_{mth} + 10\ ^{0}\mathrm{C}} \qquad (5)$$

Table 4. Classification of the de Martonne Aridity Index

de Martonne aridity index	Classification	Vegetation
$IdM \leq 5$	Arid regions, no water drainage	Extremely arid
$5 < IdM \leq 10$	Endorheic regions, water drainage does not reach the ocean	Marginal desert regions
$10 < IdM \leq 20$	Exoreic or endorheic drainage, water drainage reaches the ocean	Grasslands and shrub formations
$20 < IdM \leq 30$	Exoreic drainage, irrigation is not necessary	Forest steppes
$30 < IdM \leq 40$	Drainage is constantly peripheral to the ocean	Tree cover and forests
$IdM > 40$	Water drainage is constant and abundant	Forests occupy the entire area

Source: Ducić & Anđelković (2004); Komljenić & Kondić (2011)

As a robust method for assessing parameter trends, we employed five-year moving averages and analyzed their trends. Five-year moving averages are a statistical technique used to smoothen short-term fluctuations in data, providing a clearer view of long-term trends. This process involves calculating the average of a specific data point and the two data points before and after it, as well as the two data points before and after those, resulting in a new series of averages.

To test for the presence of linear trends in all parameters, we conducted the Mann-Kendall test. This test is suitable for time series data, denoted as x_i, where we assume they follow a linear model $x_i = f(t_i) + \varepsilon_i$. Here, $f(t_i)$ represents a continuous monotonic function of time, and ε_i is the residual with a normal probability distribution and a mean of zero. The Mann-Kendall test is based on the null hypothesis H0, suggesting that x_i is randomly distributed over time, and the alternative hypothesis H1, which suggests the existence of a monotonic trend function $f(t_i)$. The S and Z statistics, as described in Gilbert (1987), were used for the test, and the calculations were performed using the MAKESANS MS Excel macro, as extensively explained by Salmi et al. (2002).

With a significance level of 0.05, or 95% confidence, we expect the null hypothesis H0 to be rejected in favor of the alternative hypothesis H1. In practical terms, this means that the null hypothesis will be rejected if the probability of obtaining the observed statistic result by chance is less than 0.05, or in other words, if there is less than a 5% chance that the result is random.

Combining the use of moving averages with the Mann-Kendall test enhances the robustness of our analysis, providing a more reliable understanding of the long-term behavior of the examined parameters. This approach strengthens the validity of our research findings and contributes to a comprehensive assessment of trends within the dataset.

4. Results and Discussion

4.1. Temperature Regime

The temperature regime, as an indicator of the environmental thermal conditions, is primarily influenced by solar radiation, geographic location, and topography. In the Pirot Valley, the topography plays a significant role in creating local climate variations due to its slope exposures.

Based on the average monthly temperatures for Pirot during the period of 1961-2020, we calculated the mean air temperature values for each month and the annual average. The data were divided into two standard climatological periods of thirty years each: 1961-1990 and 1991-2020. The results are presented in Table 5 and Figure 1.

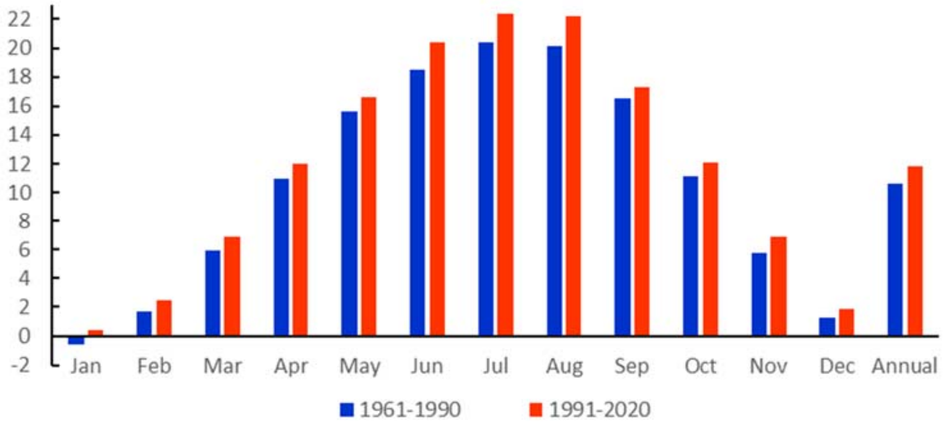
According to Gračanin's geophysical classification (Table 1), the Pirot Valley falls into the category of areas with a moderately warm climate, with an average annual temperature of 11.2 °C over the period (1961-2020). A comparison between the mean annual and mean monthly air temperatures for Pirot in the two consecutive climatological periods reveals an evident increase in temperature over time (Table 5, Figure 1). All months showed higher values in the second period, and notably, the negative January mean temperatures recorded in the first period were not observed in the second period.

Table 5. Mean Monthly and Mean Annual Air Temperatures in Pirot [°C]

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961 - 2020	-0.1	2.1	6.4	11.5	16.1	19.4	21.4	21.1	16.9	11.6	6.4	1.6	11.2
1961 - 1990	-0.6	1.7	5.9	11.0	15.6	18.5	20.4	20.1	16.5	11.1	5.8	1.3	10.6
1991 - 2020	0.4	2.5	6.9	12.0	16.6	20.4	22.4	22.2	17.3	12.1	6.9	1.9	11.8
C.R. [°C/dec]	0.3	0.3	0.3	0.3	0.3	0.6	0.7	0.7	0.3	0.3	0.4	0.2	0.4

To statistically assess the presence of a linear trend in mean temperatures, we employed the Mann-Kendall test for the period 1961-2020. The results indicated a significant increasing trend at the annual level and in all months except for November. The null hypothesis H0 (no trend) was confidently rejected in all cases with a confidence level exceeding 95%, in favor of the alternative hypothesis H1, suggesting the existence of a trend. The rejection of H0 for the annual and summer months (June, July, August) exceeded a confidence level of 99.9%. Similar results were obtained for the second climatological period, with the exception that the existence of trends in January and May temperatures could not be sufficiently confirmed (>95%). In the first period (1961-1990), the Mann-Kendall test did not confirm the existence of trends in either the annual or monthly temperatures, except for November, where the trend was confirmed with a 99% confidence. However, this trend was negative, indicating a decrease in November temperatures during this period, which ultimately led to the inability to confirm the overall trend of temperature increase, as observed in all other months. These findings are consistent with previous research and climate model predictions for this region of Serbia (Popović et al., 2009).

Figure 1. Mean monthly and mean annual air temperatures in Pirot [°C]



Based on the observed temperature differences between the two climatological periods, we calculated the change rate (referred to as C.R. in all subsequent tables) in °C per decade, as presented in Table 5. This simplified the assessment of temperature rise, in conjunction with the computed mean temperatures for the second climatological period, indicates an impending shift from a moderately warm to a warm climate within the next decade, based on Gračanin's classification.

Furthermore, the analysis of five-year moving averages of temperature consistently reveals an upward trend, demonstrating a substantial increase. The null hypothesis H0 (no trend) was confidently rejected in all cases with a 99.9% confidence level, in favor of the alternative hypothesis H1 (trend exists). These findings provide robust evidence of a progressive temperature increase in the study region.

Mean maximum and mean minimum temperatures for each period are provided in Tables 6 and 7, respectively, and visually represented in Figures 2 and 3. The observed data indicate a consistent upward trend in both mean maximum and mean minimum temperatures across all months, indicating that both summers and winters are becoming warmer.

Table 6. Mean Maximum Temperatures in Pirot [°C]

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961 - 2020	3.9	7.0	12.2	17.7	22.4	25.8	28.2	28.7	24.3	18.6	11.7	5.4	17.2
1961 - 1990	3.3	6.3	11.4	17.1	21.9	24.8	27.1	27.5	24.1	18.2	11.1	4.9	16.5
1991 - 2020	4.6	7.7	12.9	18.4	23.0	26.8	29.3	29.9	24.6	19.0	12.4	5.8	17.9
C.r. [°C/dec]	0.4	0.5	0.5	0.4	0.4	0.7	0.7	0.8	0.2	0.3	0.4	0.3	0.5

Figure 2. Mean Maximum Temperatures in Pirot [°C]

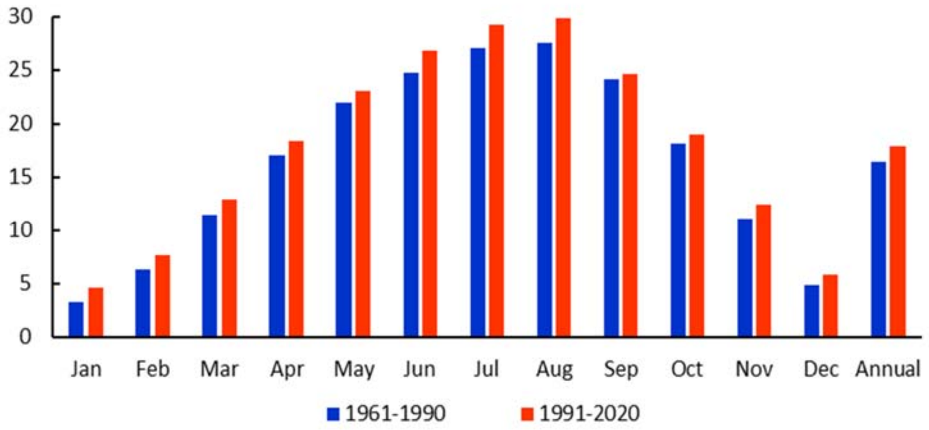
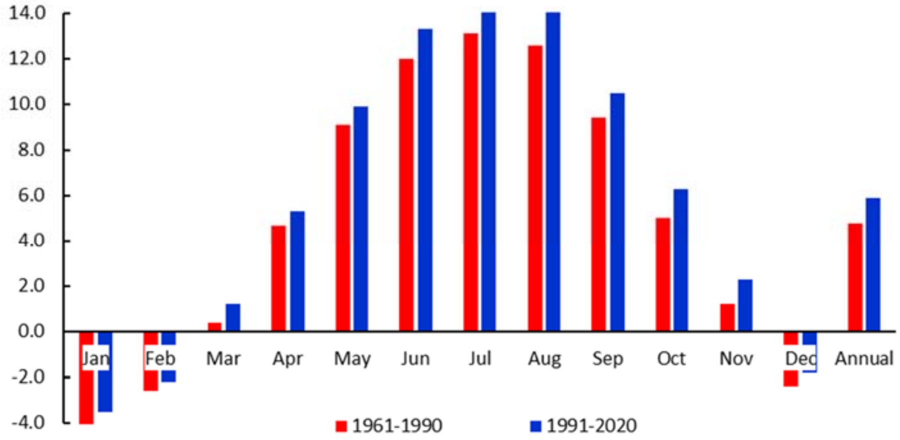


Table 7. Mean Minimum Temperatures in Pirot [°C]

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961 - 2020	-4.0	-2.4	0.8	5.0	9.5	12.6	13.9	13.5	9.9	5.6	1.8	-2.1	5.3
1961 - 1990	-4.5	-2.6	0.4	4.7	9.1	12.0	13.1	12.6	9.4	5.0	1.2	-2.4	4.8
1991 - 2020	-3.5	-2.2	1.2	5.3	9.9	13.3	14.7	14.4	10.5	6.3	2.3	-1.8	5.9
C.r. [°C/dec]	0.3	0.1	0.3	0.2	0.3	0.4	0.5	0.6	0.4	0.4	0.4	0.2	0.4

Statistical analysis has revealed statistically significant increases in the annual mean maximum temperature and mean maximum temperatures in all months, except for September, October, and November. This finding indicates that the warmest daytime temperatures are on the rise in most months of the year, contributing to overall warming trends.

Figure 3. Mean Minimum Temperatures in Pirot [°C]



Similarly, statistically significant increases have been observed in mean minimum temperatures, both the annual and monthly. This means that the coldest nighttime temperatures are also showing an upward trend, further substantiating the overall warming pattern in the region.

4.2. Precipitation Regime

The precipitation regime in the Pirot Valley is a result of various factors, including the amount, frequency, distribution, and intensity of rainfall. Precipitation plays a crucial role, particularly during the vegetative period, and is heavily influenced by the seasonal distribution of rainfall. To assess the precipitation patterns in Pirot, we calculated the average monthly and annual precipitation values for three study periods: 1961-2020, 1961-1990, and 1991-2020, as presented in Table 8 and Figure 5.

According to Azzi's geophysical climate classification (Table 1), the Pirot Valley is categorized as having a subhumid or semi-humid climate, with an average annual precipitation of 599.4 mm (1961-2020).

On a monthly scale, precipitation exhibits a significant variability, with lower amounts recorded during January and February, and higher amounts during June. A noticeable decrease in the annual precipitation is observed between the two periods, but the Mann-Kendall test does not provide sufficient evidence to confidently reject the null hypothesis (no linear trend). The situation varies across months, with some months showing decreased precipitation and others showing an increase. The most pronounced decline in precipitation occurs in November and July, while the most considerable increase is observed in October and August.

However, it is important to note that the apparent increase in August precipitation during the second period is somewhat misleading. In 2015, several days of heavy rainfall significantly boosted the total annual precipitation for that year by 30%. While such intense rainfall events can have positive impacts on hydrological conditions, they often pose challenges for agricultural production. Intense rain in a short period, or the growing irregularity in rainfall distribution, is more frequent during the second period, necessitating a more detailed analysis of the statistical increases in precipitation for specific months, particularly with regard to agriculture. Statistically, there is no significant evidence, in any period, either on a monthly or annual level, to reject the null hypothesis (H0) that there is no linear trend in precipitation, regardless of whether it shows an increasing or decreasing trend.

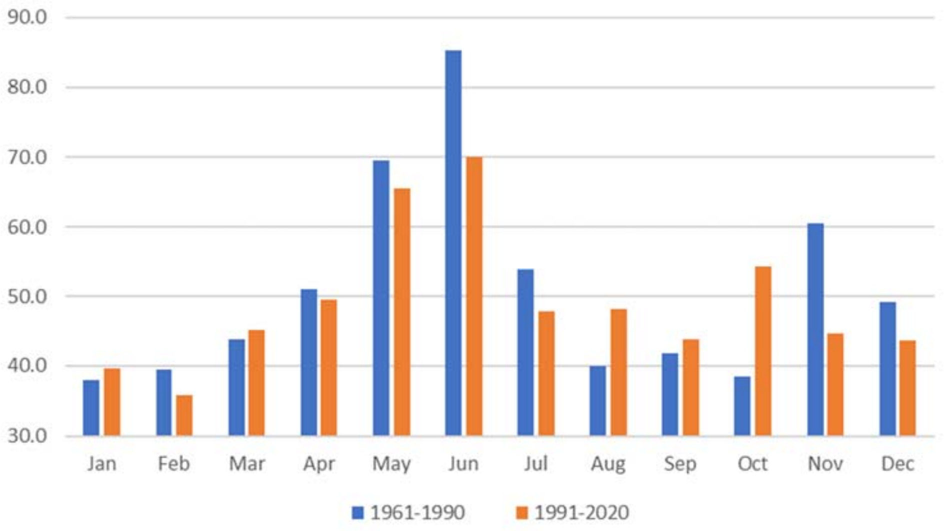
In contrast, when analyzing the trends in five-year moving averages of precipitation, June, July, and November exhibit decreasing trends, while October shows an increasing trend. Linear decreasing or increasing trends in precipitation have been confirmed for each of these months. The declining trends in June and July are of particular concern in terms of agricultural production.

Based on the difference between precipitation in the two periods, the change rate (C.R.) was calculated, representing the change in precipitation in °C per decade (Table 8). According to this simplified assessment of change and the calculated average precipitation values for the second climatological period, a shift from a subhumid to a semiarid climate is expected within the next thirty years, based on Azzi's classification.

Table 8. Mean Monthly and Mean Annual Precipitation in Pirot [mm]

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961 - 2020	38.8	37.6	44.4	50.3	67.6	77.7	50.8	44.1	42.8	46.4	52.6	46.3	599.4
1961 - 1990	38.0	39.4	43.8	51.0	69.6	85.3	53.8	39.9	41.8	38.4	60.6	49.1	610.7
1991 - 2020	39.6	35.8	45.1	49.5	65.6	70.1	47.8	48.2	43.8	54.3	44.6	43.6	588.1
C.R. [°C/dec]	0.5	-3.6	1.3	-1.5	-4.0	-15.2	-6.0	8.3	2.0	15.9	-16.0	-5.5	-22.6

Figure 5. Mean Monthly and Annual Precipitation in Pirot [mm]



4.3. *Agroclimatic Indices*

This study encompasses the calculation of Lang's Rainfall Factor, Gracanin's Rainfall Factor, and the De Martonne Aridity Index for the Pirot Valley, using the available data to gain valuable insights into the agroclimatic conditions over time. These indices, integrating the influences of precipitation and temperature, offer a comprehensive assessment of the prevailing environmental conditions and their trends.

Lang's Rainfall Factor for Pirot was computed annually during all three observation periods, and the corresponding values are presented in Table 9. Over the extensive observation period of 1961-2020, Lang's Rainfall Factor recorded a value of 53.9, while for the two standard climatological periods of 1961-1990 and 1991-2020, the factors were 57.9 and 50.0, respectively. The outcomes obtained for all three periods indicate that the climate of Pirot can be classified as semiarid, characterized by the predominance of steppes and savannas in its vegetation. Notably, there is a significant -13.6% change in the annual Rainfall Factor values between these two periods, signaling a shift towards more arid conditions. This directional trend is further supported by the results of the Mann-Kendall test, which confidently rejects the null hypothesis of no trend in Lang's Rainfall Factor at a significance level of 95%. Furthermore, when analyzing the trend of five-year moving averages of Lang's Factor, the decreasing trend becomes even more apparent, with a robust rejection of the no-trend hypothesis at a high significance level of 99.9%.

Tabela 9. Rain factor by Grachanin and Lang

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
	Grachanin												*Lang*
1961 - 2020	3.5	3.5	8.7	4.6	4.3	4.1	2.4	2.2	2.7	4.1	4.9	4.3	53.9
1961 - 1990	3.6	3.8	9.8	4.8	4.7	4.7	2.7	2.0	2.7	3.6	5.8	4.7	57.9
1991 - 2020	3.4	3.1	7.6	4.4	4.0	3.5	2.2	2.3	2.7	4.7	3.9	3.9	50.0
C.r.[%]	-5.6	-18	-22	-8.3	-14.9	-25	-18	15.	0.0	30	-33	-17	-13.6

Gračanin's Rainfall Factor is calculated annually, similar to Lang's, and thus all previous considerations are applicable to it as well. The monthly values of Gračanin's Rainfall Factor for the entire period of 1961-2020 exhibit various classifications. Specifically, only March indicates a humid climate, while the majority of months, including January, February, April, May, June, October, November, and December, demonstrate characteristics of a semiarid climate. Conversely, July, August, and September are classified as arid.

When comparing the two climatological periods, a decrease in monthly Rainfall Factor values is observed during the second period in almost all months, with the exceptions of August and October. The most significant change occurs in November, which was classified as semihumid in the first period but as semiarid in the second. Within the critical months for agricultural production, namely May, June, and July, there is a decline in the Rainfall Factor, while August shows an increase. However, the observed August increase is questionable due to the unusually high monthly rainfall in 2015.

The application of the Mann-Kendall test demonstrates a statistically significant reduction in Gračanin's Rainfall Factor on an annual basis and specifically in the month of November. Nevertheless, for the other months, it is not possible to reject the null hypothesis of no trend.

Conversely, when considering the five-year moving averages, a statistically significant declining trend is evident on an annual basis and particularly in the months of February, June, July, October, November, and December, with a strong rejection of the no-trend hypothesis at a significance level of 99.9%.

The De Martonne Aridity Index was calculated for all three observation periods, similar to the other indices, and its values are presented in Table 10. Over the period 1961-2020, the annual index registered a value of 28.3, classifying the Pirot Valley as an exoreic drainage region with prevalent forest-steppe vegetation. As the index value approaches 30, irrigation becomes unnecessary as a constant measure in these areas, except for leguminous grass formations or meadows, and water-demanding crops such as peppers and cereal crops.

When comparing the two climatological periods, the De Martonne Aridity Index recorded values of 29.7 and 27.0, respectively, also placing the Pirot Valley within exoreic drainage regions. However, a notable 9.1% reduction in the aridity index was observed during the second thirty-year period.

On a monthly basis, the De Martonne Aridity Index, over the entire observation period, exhibits variations across different categories. Winter months, January and December, fall into the category of months with abundant water runoff and forest vegetation covering almost the entire area, with cereal crops at risk of excessive moisture. Here, drainage is necessary as a permanent agrotechnical measure. Months characterized by constant peripheral drainage are February, March, May, June, and November. Vegetation-wise, trees gradually expand their presence. April and October are classified as months with exoreic drainage and forest-steppe vegetation. July, August, and September are characterized by either exoreic or endoreic drainage and steppe vegetation. Irrigation is mandatory during these months as an agrotechnical measure.

Tabele 10. de Martonne Aridity Index in Pirot

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1961 - 2020	51.6	40.0	33.5	28.6	31.6	32.1	19.7	17.3	19.7	26.1	39.6	49.1	28.3
1961 - 1990	55.4	43.1	34.4	29.6	33.4	36.3	21.5	16.2	19.6	22.0	46.5	54.0	29.7
1991 - 2020	47.7	36.8	32.5	27.6	29.7	27.9	17.8	18.5	19.8	30.1	32.8	44.2	27.0
C.r.[%]	-14	-15	-5.5	-6.8	-11	-23	-17	14	1.0	37	-29	-18	-9.1

Analyzing the monthly De Martonne Aridity Index between the two periods reveals a decrease in its values over time in all months, except for August, September, and October. During the second period, the reduction shifts some months into different categories.

For instance, while in the first period, January, February, November, and December are classified as months with abundant runoff and forest vegetation, in the second period, only January and December fall into this category, while February and November move to a drier category with constant peripheral drainage and forest vegetation. Similar considerations apply to other months.

The most significant decrease in the index, by 29%, is recorded in November, and it is the only month where a negative trend has been proven by the Mann-

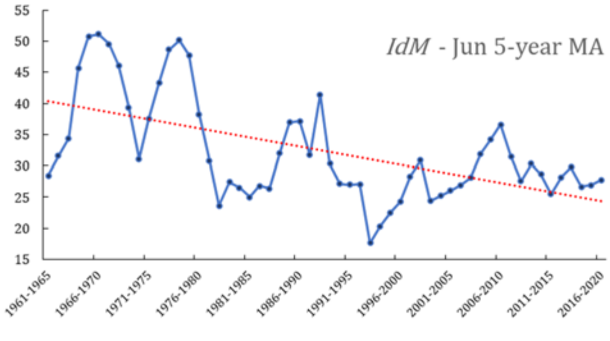
Kendall test. The aridity indices for May, June, and July, which are vital for agriculture, are notably declining, but the hypothesis of no trend cannot be confidently rejected.

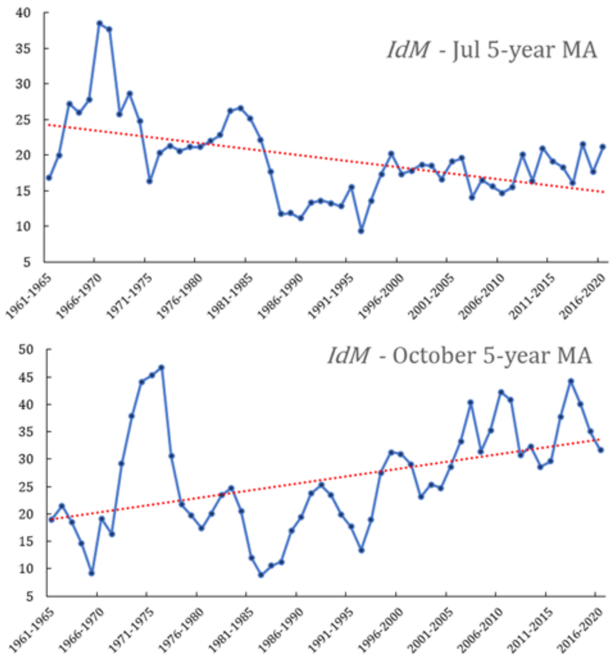
Analyzing the trend of five-year moving averages of the De Martonne Aridity Index provides a reliable indicator of long-term changes in aridity. The Mann-Kendall test was applied to these five-year moving averages to statistically assess the presence of trends. The test results reveal important insights into the changing aridity conditions in the Pirot Valley.

On an annual basis, the Mann-Kendall test confidently rejects the null hypothesis of no trend in the De Martonne Aridity Index, indicating a significant shift in aridity levels over time. Specifically, in February and December, the test shows a decreasing trend in aridity with a significance level of 95%, implying that these months are experiencing reduced dryness over the years. Moreover, in June, July, and October, the Mann-Kendall test demonstrates a compelling decreasing trend in aridity at an even higher significance level of 99.9%. This signifies that these months are becoming progressively drier, which has important implications for agricultural practices and water resource management.

Across all months and on an annual basis, the average trend of the De Martonne Aridity Index is decreasing, further corroborating the shift towards drier conditions in the Pirot Valley. However, it is noteworthy that October exhibits a contrasting trend, with the index showing a rising trend over the years. This increasing aridity in October is a significant finding, as it stands out from the overall decreasing trend observed in other months. Properly interpreting this deviation and its potential impact on local ecosystems and agriculture requires further investigation.

Figure 5. 5-year Moving Average of de Martonne Aridity Index in Pirot for Jun, Jul and October





To visualize the trends more effectively, Figure 5 depicts the five-year moving averages of the De Martonne Index for the months of June, July, and October. The red trend line helps visually highlight the direction and magnitude of the observed changes. The clear downward trend for June and July, coupled with the upward trend in October, indicates that the Pirot Valley's climate is increasingly transitioning towards aridity, especially during the summer months. This pattern is a matter of concern for the region's agricultural productivity, water resource management, and ecosystem dynamics.

5. Conclusion

The problems caused by climate change are numerous and have far-reaching impacts on the economy and economic development. Agriculture is particularly vulnerable as it is highly exposed to the negative effects of climate change.

The aim of this research was to determine whether there are changes in agroclimatic conditions in the Pirot Valley due to climate change and potential impacts on the future of agricultural production in this region. Agroclimatic conditions of a specific territory are best defined by considering fundamental climatic elements and their combination through agroclimatic indices.

The data unequivocally indicate that alongside the temperature increase caused by global warming, there are significant changes in agroclimatic conditions in the Pirot Valley.

The impact of climate change on the Pirot Valley's agricultural conditions is multifaceted and is reflected in key climatic parameters, including temperature, precipitation, and aridity indices. Our investigation has shed light on significant trends and patterns that warrant further attention and proactive measures to address the challenges posed by changing agroclimatic conditions.

Our analysis of temperature trends in the Pirot Valley over the observation period of 1961-2020 revealed a consistent and pronounced increase in temperatures. This rising temperature trend aligns with global warming phenomena and is consistent with the predictions of climate models (Petrović, 2008). The elevation in average temperatures can have severe implications for agriculture, as it can lead to changes in crop phenology, increased water demand, and heat stress on plants, ultimately influencing crop yields and agricultural productivity.

The evaluation of precipitation trends in the Pirot Valley also disclosed noteworthy patterns. While the annual precipitation did not exhibit a significant overall trend, a more granular examination highlighted considerable variability across individual months. June, July, and November demonstrated declining trends in five-year moving averages, indicative of potential drier conditions during these crucial months for agricultural production. Conversely, October displayed an increasing trend in precipitation, which could have implications for specific crops that rely on adequate water supply during that period.

Our assessment of the Lang's Rainfall Factor, Gracanin's Rainfall Factor, and the De Martonne Aridity Index revealed a notable shift towards an increased aridity in the Pirot Valley. This transformation is evident in both the Lang's and De Martonne's indices, with significant decreases in the five-year moving averages, indicating progressively drier conditions. The De Martonne Aridity Index, specifically, experienced a substantial 9.1% reduction during the second thirty-year period. These findings corroborate predictions from climate models (Petrović, 2008) and are consistent with studies conducted in other regions of Serbia (Dimikić, 2022; Radaković, 2018; Milentijević, 2018; Kutiel, 2020).

Overall, the changing climate in the Pirot Valley necessitates immediate attention and adaptive strategies in the agricultural sector. Sustaining agricultural productivity in the face of rising temperatures and evolving precipitation patterns requires targeted measures, such as the introduction of heat-resistant crop varieties, improved irrigation practices, and optimal water resource management. Furthermore, promoting sustainable agricultural practices, integrating climate-resilient technologies, and enhancing farmers' adaptive capacities are essential steps in ensuring the long-term viability of agriculture in the Pirot Valley and other comparable regions facing similar agroclimatic challenges. As climate change continues to shape the future, proactive and science-based approaches will play a pivotal role in safeguarding food security and sustaining agricultural livelihoods.

Moreover, collaboration between government agencies, research institutions, and local communities is essential for the successful implementation of adaptation strategies. By fostering partnerships and sharing knowledge, innovative solutions can be developed to mitigate the adverse effects of climate change on agriculture.

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UTICAJ KLIMATSKIH PROMENA NA POLJOPRIVREDNU PROIZVODNJU I AGROKLIMATSKE USLOVE U PIROTSKOJ DOLINI

Rezime: Ovo istraživanje je motivisano činjenicom da su klimatske promene u poslednjim decenijama značajno uticale na različite aspekte životne sredine i društva. Jedan od najranjivijih sektora na klimatske promene je poljoprivreda, budući da se intenzivno oslanja na vremenske uslove. Povećanje globalnih temperatura i sve učestaliji ekstremni vremenski događaji izazvali su značajne promene u biljnom svetu, utičući na njihovu fizonomiju, distribuciju, obilnost. Ovi faktori zajedno dovode do promena u agroklimatskim uslovima poljoprivredne proizvodnje. Cilj ovog istraživanja je da se utvrdi da li su slične promene prisutne u Pirotskoj kotlini, s obzirom na to da klimatski uslovi, zajedno sa geografskim položajem i kvalitetom zemljišta, igraju ključnu ulogu u uspešnom gajenju useva i postizanju visokih prinosa. Za ovu analizu, korišćeni su podaci Republičkog hidrometeorološkog zavoda Srbije za meteorološku stanicu Pirot u periodu 1961-2020. Detaljno su analizirane godišnje i mesečne temperature vazduha, padavine, agroklimatski indeksi i identifikovan je njihov trend. Uporedno su analizirana dva standarna klimatološka perioda 1961-1990 i 1991-2020, gde je pokazano da uticaj klimatskih promena postoji i da direktno utiče na kvalitet i kvantitet prinosa i razvoj poljoprivrede Pirotske kotline.

Ključne reči: klimatske promene, poljoprivreda, agroklimatski uslovi, Pirotska kotlina

Author biographies

Nataša Martić Bursać, PhD was born in Niš in 1973, where she completed her primary and secondary education. In 2000, she graduated from the Faculty of Science and Mathematics at the University of Priština, Department of Geography. She completed her postgraduate studies at the Faculty of Geography, University of Belgrade, obtaining a Master's degree in 2010, and earned her PhD at the Faculty of Science and Mathematics, University of Niš, in 2015. Currently, she holds the position of the Associate Professor at the Department of Geography, Faculty of Science and Mathematics, University of Niš. Within the Physical Geography Chair, her scientific research focuses on climatology, climate change, applied climatology, agroclimatology. She is engaged in various scientific projects in the field of physical geography and has published numerous papers in prominent international journals. Additionally, she has actively participated in various national and international scientific conferences.

Ljiljana Stričević, PhD was born in Kruševac in 1977. where she completed her primary and secondary education. In 2003, she graduated from the Faculty of Geography, University of Belgrade, and obtained a Master's degree in 2010. In 2015, she earned her PhD at the Faculty of Science and Mathematics, University of Niš. Dr. Stričević is currently an Associate Professor at the

Department of Geography, Faculty of Science and Mathematics, University of Niš, where she has been employed since 2004. As the Head of the Physical Geography Chair, she conducts research in the fields of hydrology, climatology, and natural disasters. Dr. Stričević teaches courses at the undergraduate and master's academic levels and is actively involved in extracurricular activities at the Faculty. She is engaged in a scientific project and has published numerous papers in both international and domestic journals. Moreover, she has actively participated in various national and international scientific conferences.

Milena Gocić, PhD was born in Niš in 1984, where she completed her primary education and "Svetozar Marković" Gymnasium. She finished her undergraduate studies at the Department of Geography, Faculty of Science and Mathematics, University of Niš. She obtained her Master's and PhD degrees at the Faculty of Geography, University of Belgrade. Currently, M. Gocić is an Assistant Professor at the Department of Geography, Faculty of Science and Mathematics, University of Niš, where she has been working since 2010. As a member of the Physical Geography Chair, she conducts research in the fields of geomorphology, climatology, soil geography, and natural disasters. Dr. Gocić teaches courses and exercises at the undergraduate and master's academic levels and actively participates in extracurricular activities. She has published numerous papers in international and domestic journals and presented her research at scientific conferences both in Serbia and abroad.